

SEGREGATION OF COAL PARTICLES DURING CHARGING INTO COKING TOWER

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ABSTRACT

This study investigates coal particle segregation in an industrial coking plant, analysing particle size and key quality parameters (ash, volatile matter, sulfur). Unlike previous mathematical or lab-based studies, it provides real-world data to optimize coal preparation. Findings show uneven ash distribution across size fractions: the 25 - 50 mm fraction has the highest ash content (6.8 - 32.1 %, average 13.1 %), while lower values appear in the 0.5 - 6 mm range (6.9 - 7.3 %). Fine fractions (< 0.5 mm) exhibit elevated ash levels (average 10.9 %, max. 15.1 %).

Despite stable coal charge properties during loading, variations across tower sections highlight challenges in achieving uniformity. Differences in particle size, volatile matter, and ash content from central to peripheral rows emphasize the need for improved loading strategies. This study underscores the critical role of the loading and distribution stages in preparing a uniform coal charge for coking offers practical recommendations to enhance coal preparation and coke production efficiency.

***Keywords:** segregation, coking tower, ash content, particle size classes, sampling, distribution, granulometric composition.*

INTRODUCTION

Coal segregation involves separating coal particles into fractions based on physical and chemical properties, such as particle size, impurity content by specific gravity, or other quality characteristics. This process is vital in industries utilizing coal as fuel and raw materials, particularly energy and metallurgy. Proper segregation enhances resource efficiency, reduces costs, improves productivity, and minimizes environmental risks, though advanced technologies and careful management are necessary to mitigate ecological impacts [1].

Despite the dominance of coal in the global energy landscape, the depletion of high-quality reserves and reliance on harder-to-process coal exacerbate

environmental challenges and lead to significant carbon resource losses. Clean and efficient utilization of such coal requires segregation and beneficiation methods, optimizing resources, and supporting key industries like metallurgy, energy, and chemicals [2].

However, coal segregation faces challenges, including expensive specialized equipment and environmental concerns. Segregation processes, such as flotation, can pollute water through chemical reagents, and low-quality coal often results in significant waste. Innovations such as automated control systems and environmentally friendly materials aim to improve process efficiency and reduce negative impacts [3].

Scientific research explores methods for effective coal separation by size, density, and chemical properties.

For instance, dry beneficiation methods are gaining relevance in regions with limited water resources [4]. Separation by particle size often uses mechanical sieving, effectively distinguishing large and small fractions for further processing [5 - 7]. Silva et al. emphasize the importance of particle size distribution, noting that inert materials are concentrated in more significant fractions, while reactive macerals are softer and more prone to crushing. Excessive inert substances can cause coke failures, while smaller reactive particles (< 0.15 mm) decrease swelling and fluidity, reducing coke mechanical stability [8].

Density-based separation methods, like settling and dense media separation, exploit differences in density between coal and bulk minerals. However, particle size strongly influences settling velocity, making these methods less effective for small particles [9, 10]. Adjusting the bulk density of coal mixtures for coking involves controlling particle size, grinding level, drying, or moistening. Balancing these factors optimizes coke production, increases yield, reduces heat consumption, and improves coke quality [5, 11 - 13].

Research on mixing and segregation explores factors like initial humidity, mixing time, and temperature. One study concluded that the moisture content of fine particles decreases with lower initial moisture in coarse particles or increased mixing time. However, factors like water pressure gradient and particle properties have limited influence on re-adsorption efficiency [14].

The works of Mianowski et al. and Miroshnichenko et al. are devoted to solving the problem of optimal compaction of the charge in the gravity system, considering the effects of segregation for the coke formation process. It states that specific technological recommendations limit the particle size composition of the coal mixture for the gravity system. Most often, it is the fraction of grains with a size of less than 3 mm and the fraction of tiny grains of less than 0.5 mm, which should strive for the minimum possible, as well as the total moisture content below 10 %. Practice shows that for the top filling system, the degree of grinding, as a fraction of grains smaller than 3 mm, is 73 - 87 %, while the share of the dust fraction does not exceed 42 % [15, 16].

Studies conducted using a planned experiment show that for moisture content of $W^t = 6 - 8$ %, the maximum compaction is achieved for grains of two sets of grains of 0.5 - 1 mm and more than 3 mm in an approximate

ratio of 1:1 [17].

Newcastle University research led by McPherson demonstrates the effectiveness of Reflex Classifiers, which improve flow stability and use vibration to improve separation quality. This technology allows you to reduce the ash content to 10 % with significant preservation of valuable materials, which is economically beneficial when access to water is limited [18]. This research is also relevant from the point of view of using aero classifiers, which distribute coal particles depending on the size and density, which allows for improvement of the product's final quality, reducing the content of undesirable components.

Spontaneous coal ignition in bunkers is a complex process influenced by segregation effects. Studies using numerical modelling show that segregation shortens the self-ignition period and significantly impacts high-temperature zone placement. Further field experiments are needed to refine these findings for practical applications [19].

Fu et al. were aimed at evaluating the mixing and segregation of binary mixtures of solid particles for dry coal enrichment, and the results were interpreted from the point of view of the axial distribution of solids [20]. The results of the experiment demonstrated that the segregation of particles becomes more evident with an increase in the particle density ratio. The behaviour of mixing and segregation of particles of binary mixtures turned out to be less sensitive to changes in the ratio of particle sizes than to the ratio of particle density. This conclusion is also confirmed by the authors of studies [21 - 24]. However, as Fu et al. in their work, these results were also obtained with the help of process simulation, and the layer's height did not exceed 30 cm [20].

For instance, fine coal particles show quadratic mass fraction increases along layer height, while loose rock particles settle at the bottom. However, segregation efficiency diminishes with smaller particle sizes [25].

The paper's authors conducted a fascinating study of the influence of the maceral composition of coal on the processes of its segregation and crushing [26]. Based on experiments, it was established that under the same conditions, vitrinite is more easily subjected to deeper crushing than inertinite. Due to their smaller size, vitrinite and ash tend to leave the cyclone separator, and inertinite and ash, due to their high density, tend to accumulate in the lower part of the coal dump. The segregation of

macerals occurs in the grinding process and significantly affects the characteristics of coal powder. Regarding surface functional groups, maceral segregation is more influential than mechanochemical effects.

Such authors as Oshitani et al., Yang et al., Surowiak et al., and van Netten are also devoted to modelling the segregation process of coal particles [27 - 30]. So, modern scientific works demonstrate a wide range of approaches to coal segregation, which contribute to increasing the quality of the coal product and reducing dependence on water resources. Still, as we have seen, all of them are either mathematical modelling or process modelling in limited laboratory conditions, and some of the listed authors directly indicate the need for further experiments in industrial conditions. We had the opportunity to study the process of coal segregation in the actual conditions of an industrial coke-chemical enterprise.

Therefore, this study aimed to investigate the process of coal segregation in the conditions of an actual industrial coke-chemical enterprise, both by size and by the main parameters of coal quality, such as ash content, volatile matter, sulfur content, etc. This will make it possible to confirm or refute the distribution patterns of coal particles previously established in laboratory conditions and / or by mathematical modelling. In turn, these patterns will optimize the industrial preparation process of coal for further use.

EXPERIMENTAL

Materials

The study focused on coal concentrates forming the raw material base of Coal Preparation Workshop № 2 (CPW - 2) at Private Joint Stock Company "Avdiivka Coke Plant" (PJSC "ACP"): They include four coals - "A," "B," "C," "D" of a low stage of metamorphism ($R_0 < 0.9\%$); 7 components of coal of the middle stage of metamorphism (of which five components of fatty coal - "E," "F," "G," "H," "I" ($0.9\% < R_0 < 1.19\%$) and two coking coal - "J," "K" ($1.2\% < R_0 < 1.49\%$), as well as one lean coal - "L" of a high stage of metamorphism ($R_0 > 1.5\%$).

The presented coal concentrate samples were analysed using a set of standardized methodologies, including technical analysis (A^d , S^d , V^d , V^{daf}), petrographic analysis (R_0 , Vt , Sv , I , L , $\sum FC$, vitrinite reflectogram), and granulometric analysis (> 50 ; $25 - 50$; $13 - 25$; $6 - 13$; $3 - 6$; $1 - 3$; $0.5 - 1.0$; < 0.5 mm). These

analyses included determining ash content, volatile matter in particle size classes, the Hardgrove grindability index, and the Roga index.

Methods

To determine the quality parameters of coal and coal charges, which were determined and are given in section 3, the following standardized methods were employed:

Sampling and sample preparation for laboratory tests according to ISO 18283:2022 Coal and coke - Manual sampling; DSTU 4096 - 2002 Coal, lignite, anthracite, combustible shales, and coal briquettes.

Methods for sampling and sample preparation for laboratory tests according to DSTU 8699:2016 (ISO 18283:2022) Hard coal, anthracite, and coke. Manual sampling.

Proximate analysis data (W^a , A^d , S^d , V^d , V^{daf}) according to ISO 17246:2010 Coal - Proximate analysis; ISO 334:2020 Coal and coke - Determination of total sulfur; ISO 589:2008 Methods for determining the total moisture content of hard coals (two-stage and single-stage methods); ISO 1170:2020 Coal and coke - Calculation of analyses to different bases.

Petrographic analysis data (R_0 , Vt , Sv , I , L , $\sum FC$, vitrinite reflectogram) according to DSTU 7722:2015 Hard coal. Method for determining plastometric parameters; ISO 7404 - 3:2009 Methods for petrographic analysis of coals - Part 3: Determining maceral group composition; ISO 7404 - 5:2009 Methods for petrographic analysis of coals - Part 5: Determining the reflectance of vitrinite microscopically.

Granulometric analysis data (> 50 ; $25 - 50$; $13 - 25$; $6 - 13$; $3 - 6$; $1 - 3$; $0.5 - 1.0$; < 0.5 mm; ds) according to ISO 1953:2015 Hard coal - Size analysis by sieving.

Hardgrove grindability index (HGI) according to ISO 5074:2015 Hard coal - Determination of Hardgrove grindability index.

Caking ability (Roga index) according to DSTU 7723:2015 (ISO 335:1974) Hard coal - Determination of caking power by Roga test.

Coal classification according to DSTU 3472:2015: Coal brown, complex, and anthracite. Classification.

Experiment execution

The coal tower is designed to receive and load into compartments, store prepared coal charges, and

supply the hoppers of the coal-charging car. This structure represents a bunker-type facility comprising multiple compartments designated for coal charge storage. The upper bunker-level spaces of the coal tower accommodate stationary technological equipment intended for receiving and distributing coal charge across the sections of the tower. This equipment is integral to the coal preparation department. The facility operates in a mode that prepares and supplies the coal charge to the tower, distributing it across its sections. The technological equipment is required to ensure uniform distribution and loading of the sections while minimizing the effects of coal charge segregation by particle size. To support the continuous and stable operation of the coking and coal preparation facilities, the coal tower must maintain a storage capacity sufficient for operating the furnaces in design mode for two to three shifts. The coal tower is divided into sections to facilitate regular inspections and repairs of internal walls, dispersers, and gates and periodic cleaning of coal charge adhering to or suspended on the inner walls. The sections are equipped with specialized devices for pneumatically dislodging stuck coal charges. At PJSC “ACP,” a two-section coal tower has a stationary reversible belt conveyor and valves for distributing the charge across the sections. During the experiment, coal charge samples were collected from the coal tower and loaded into the hoppers of the coal-charging machine. Sampling was conducted

from rows 1, 4, and 5 of sections 1 and 2.

Fig. 1 depicts the schematic layout of the two-section coal tower for batteries No. 7 - 8 at PJSC “ACP” featuring a stationary reversible conveyor and charge distribution chutes.

The analysis of the section and row layout indicates that row 5 of section 1 and row 5 of section 2 are close to the loading point, while row 1 of section 1 is farther away. The top of the coal tower for batteries No. 7 - 8 is not equipped with a discharge car, resulting in section 1 being filled only after section 2 of the coal tower is completely loaded.

At the start of the experiment, all coal concentrates included in the coal charge were sampled and analysed. Once the coal preparation department completed the preparation of the coal charge comprising stages such as preliminary and final crushing, component dosing, and mixing, the charge was transported to the coal tower of batteries No. 7 - 8 using a belt conveyor. At this stage, samples were simultaneously collected to determine the initial parameters of the charge. Sampling was performed directly from the conveyor belt before its transfer into the coal tower. In the next stage, samples of the coal charge loaded into the hoppers of the coal-charging machine were taken from different sections and rows of the coal tower over six hours. The final stage involved analysing the collected samples, comparing the results, and forming conclusions.

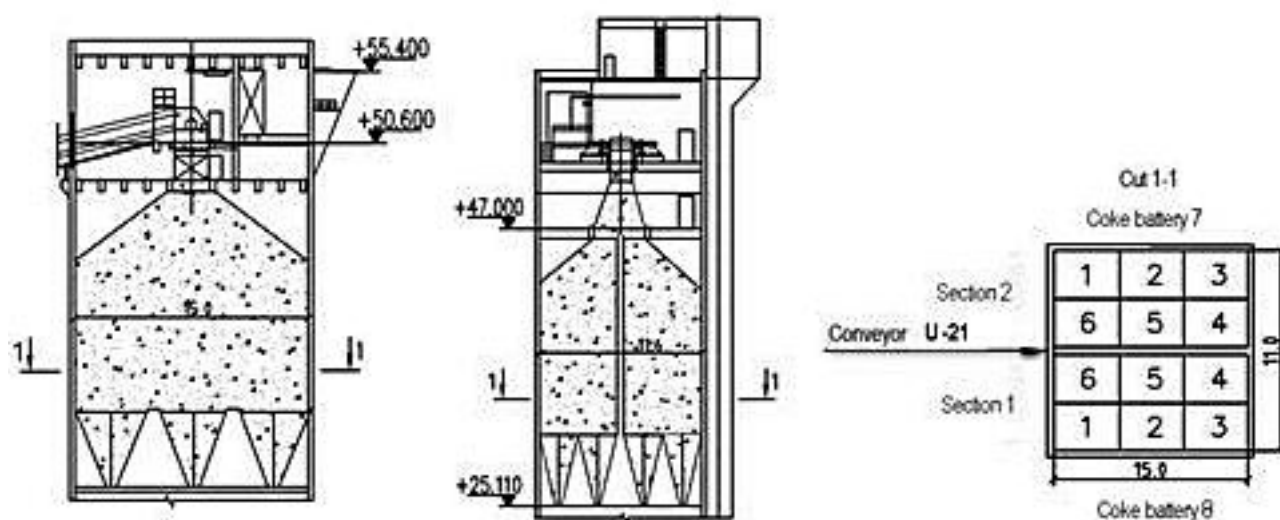


Fig. 1. Coal tower with chutes and valves for charge distribution.

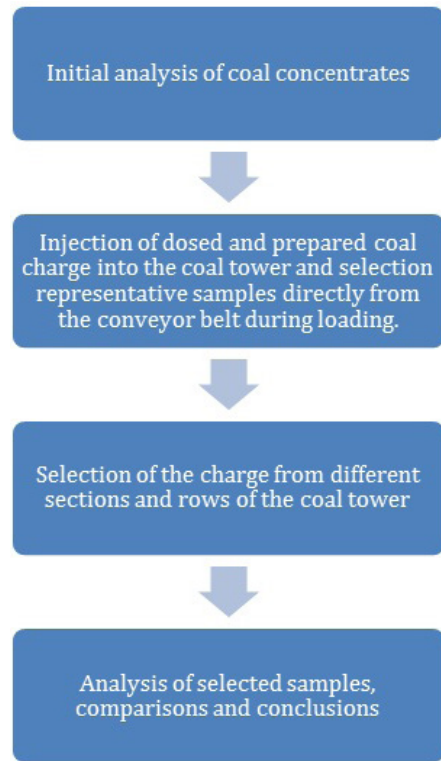


Fig. 2. General block diagram of the experiment.

RESULTS AND DISCUSSION

Table 1 presents the studied coal concentrates' technological properties and petrographic characteristics.

Coal of a low stage of metamorphism ($R_0 < 0.9\%$) is characterized by high volatile matter (38.6 - 40.1 %), a plastic layer thickness of 5 - 10 mm, sanitized components content of 18 - 26 %, and an average random vitrinite reflectance of 0.65 - 0.71 %. This coal group demonstrates the highest strength, with a Hardgrove Grindability Index (HGI) ranging from 35 to 51.

Ukrainian fatty coals "F" and "H" contain the highest sulfur content among all the samples, ranging from 1.92 % to 2.12 %. Additionally, these samples exhibit the highest Roga caking ability (84 - 86) and maximum plastic layer thickness (26 mm and 27 mm, respectively).

Coking coal has typical volatile matter of 21.8 - 28.2 %, plastic layer thicknesses of 13 - 15 mm, and vitrinite reflectance values of 1.14 - 1.46 %.

The coal "L" of a high stage of metamorphism ($1.2\% < R_0 < 1.5\%$) contains the lowest volatile matter (17.8 %) and the highest average random vitrinite reflectance (1.57 %).

Table 1. Technological properties and Petrographic characteristics of coal concentrate in the raw material base of CPW - 2 PJSC "ACP."

№	Component name	Proximate Analysis, %				Plastometric indices, mm		Hardgrove Grindability index, units	Roga index, units	Petrographic composition (excluding mineral impurities), %					Avg. reflectance of vitrinite, %
		W ^a	A ^d	S ^d _r	V ^{daf}	x	y			Vt	Sv	I	L	ΣFC	
1	A	2.4	9.0	0.59	40.1	45	10	35	52	72	1	25	2	26	0.65
2	B	1.9	8.1	0.52	39.5	44	10	51	56	73	1	24	2	25	0.71
3	C	2.7	9.2	0.63	39.6	40	5	51	17	81	0	18	1	18	0.65
4	D	1.9	7.7	0.54	38.6	34	10	49	51	76	1	22	1	23	0.68
5	E	1.0	8.7	0.64	32.1	20	15	56	76	87	0	10	3	10	1.07
6	F	1.0	7.6	2.12	32.0	9	26	67	86	93	0	5	2	5	1.07
7	G	0.9	7.2	1.02	32.8	22	18	67	81	82	0	16	2	16	1.03
8	H	1.0	7.4	1.92	30.5	4	27	78	84	90	0	9	1	9	1.08
9	I	1.0	8.5	0.77	28.2	16	13	67	68	89	0	9	2	9	1.14
10	J	1.0	7.3	1.77	21.8	10	14	91	68	91	0	9	0	9	1.46
11	K	1.0	8.2	1.79	22.9	12	15	84	70	92	0	8	0	8	1.40
12	L	0.7	9.0	0.74	17.8	11	10	80	44	78	1	21	0	22	1.57

All studied coal samples are petrographically homogeneous, with the total sanitized component content (ΣFC) ranging from 5 % to 26 %.

Analysing Table 2, the raw material base of CPW - 2 at PJSC “ACP” contains coal with significant differences in sieve composition.

For instance, coal concentrates “H,” “J,” and “K” have PJSC “ACP” over 70 % of particles in the 0 - 3 mm size class, indicating the necessity of using screening devices to separate fine fractions and prevent additional grinding and “self-pulverization.”

In contrast, coal concentrates “A,” “B,” “C,” “D,” “E,” and “G” are coarse ($d_s = 6.9 - 14.8$ mm) with grinding levels of 18.5 - 40.6 %. These require thorough grinding to achieve an overall charge grindability of 80 ± 2 %. Other coal samples exhibit intermediate characteristics.

As observed from the data in Table 3 and Fig. 3, the ash content distribution across particle size classes is uneven. The 25 - 50 mm size class has the highest average ash content at 13.1 %, with highly variable values ranging from 6.8 % to 32.1 %. The lowest ash content is found in the following size classes: 0.5 - 1 mm: 7.3 %; 1 - 3 mm: 6.9 %; 3 - 6 mm: 7.3 %. Similarly, the coarsest size class (> 50 mm) shows low ash content values, ranging between 6.6 % and 7.5 %. However, this size class is the least representative in the dataset, as it was present in only two of the twelve analysed samples.

At the same time, the ash content of the fine size classes (< 0.5 mm) in the sampled coal is significantly higher than that of the medium size classes, with an average value of 10.9 % and reaching a maximum of 15.1 %. This result confirms the data obtained [31], where the model uses computer-controlled scanning electron microscopy data sets of the target coal’s ash analysis to determine the mineral inclusion, mineral exclusion, and organically associated TE content, which are then modelled using a semi-random mineral placement approach. This trend is clearly illustrated in Fig. 4, which shows the ash content distribution of coal particles in the size range of 0.25 - 4.5 mm.

Considering this, it can be hypothesized that excessive grinding of coal, resulting in an increased proportion of particles smaller than 0.5 mm, may lead to “self-pulverization” of the charge and, consequently, a decline in its quality. Our findings align with those of previous studies conducted by Li et al., which investigated the effects of coal’s maceral composition on its segregation and crushing processes [19]. They also partially concur with the conclusions of Miroshnichenko et al. regarding particle size distribution linked to the petrographic characteristics of the material [6].

A study was conducted to evaluate the actual segregation of the coal charge in the coal tower of batteries No. 7 - 8 at PJSC “ACP”.

For this purpose, coal charge samples were collected

Table 2. Particle size distribution of coal concentrates in the raw material base of CPW - 2 PJSC “ACP”.

№	Component name	Particle size distribution (mm), %									Average particle diameter, mm
		> 50	50 - 25	13 - 25	6 - 13	3 - 6	1 - 3	0.5 - 1	< 0.5	< 3	d_s
1	A	1.7	9.6	15.7	19.7	15.6	20.0	5.5	12.2	37.7	10.9
2	B	-	2.1	14.4	27.2	18.1	16.0	5.2	17.0	38.2	7.3
3	C	-	4.8	10.4	22.5	21.7	20.3	6.8	13.5	40.6	7.4
4	D	2.8	15.1	19.9	20.7	23.0	9.3	2.5	6.7	18.5	14.8
5	E	-	4.6	8.1	15.2	42.8	11.7	4.2	13.4	29.3	6.9
6	F	-	0.9	3.6	12.0	40.7	16.6	8.1	18.1	42.8	4.4
7	G	-	5.9	18.0	24.3	17.8	16.3	4.7	13.0	34.0	9.1
8	H	-	-	2.4	8.4	11.3	24.8	15.2	37.9	77.9	2.5
9	I	-	2.4	4.5	10.6	15.1	25.0	7.5	34.9	67.4	4.1
10	J	-	1.4	3.1	7.7	13.2	27.9	11.5	35.2	74.6	3.2
11	K	-	1.2	3.3	8.1	11.2	22.6	11.1	42.5	76.2	3.0
12	L	-	5.2	7.8	12.7	11.6	20.2	8.4	34.1	62.7	5.7

Table 3. Ash content in size fractions of coal concentrates in the raw material base of CPW - 2 PJSC "ACP".

№	Component name	Ash content (A^d), %									
		Total	Particle size distribution (mm),								
			> 50	25 - 50	13 - 25	6 - 13	3 - 6	1 - 3	0.5 - 1	< 0.5	< 3
1	A	9.0	6.6	8.9	6.4	6.7	7.4	7.5	9.0	13.9	9.8
2	B	8.1	-	12.0	6.9	7.7	8.0	8.0	7.8	9.9	8.8
3	C	9.2	-	16.3	7.2	6.4	7.4	7.7	12.1	15.1	10.9
4	D	7.7	7.5	10.0	7.4	6.2	6.2	7.0	9.2	14.5	10.0
5	E	8.7	-	17.1	12.3	8.6	10.0	7.9	7.6	10.0	8.8
6	F	7.6	-	8.0	5.2	6.0	6.9	6.8	6.3	8.4	7.4
7	G	7.2	-	8.7	6.8	5.9	5.5	6.5	6.8	13.2	9.1
8	H	7.4	-	-	9.0	6.4	6.6	5.9	5.8	9.4	7.6
9	I	8.5	-	9.6	8.4	7.5	6.9	5.5	4.7	11.5	8.5
10	J	7.3	-	6.8	6.3	5.9	5.7	5.7	5.6	8.2	6.9
11	K	8.2	-	32.1	16.2	11.8	7.5	6.1	5.9	8.7	7.5
12	L	9.0	-	14.2	14.1	15.2	9.7	8.1	6.3	7.9	7.8

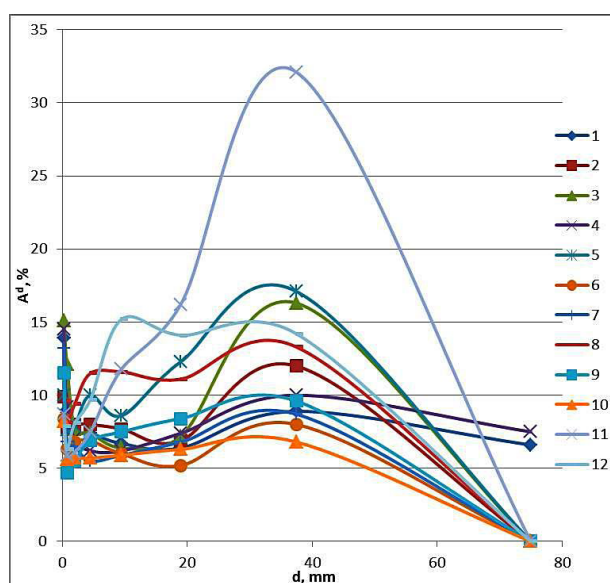


Fig.3. Distribution of coal ash content across particle size classes.

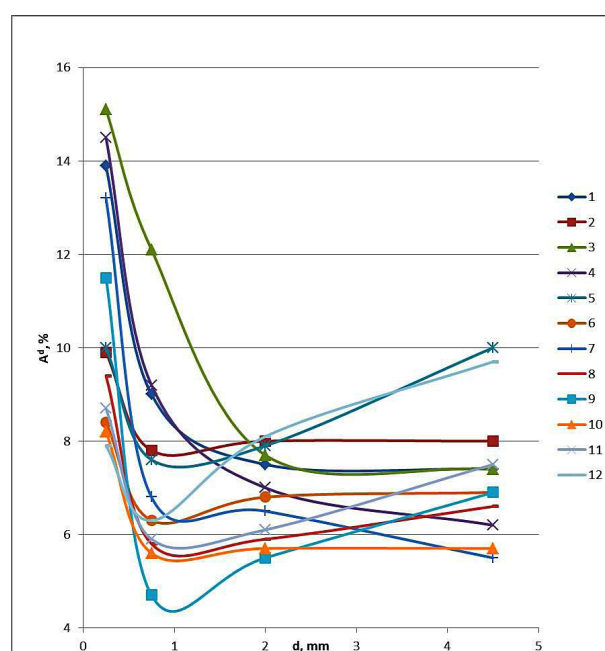


Fig.4. Distribution of coal ash content within the particle size range of 0.25 - 4.5 mm.

during loading into the coal tower and from the charge loaded into the hoppers of the coal-charging machine. Sampling was carried out from different sections and rows of the coal tower over a six-hour period.

The stage of metamorphism and component composition of the coal charge is presented in Table 4.

In the Tables 5 and 6 shows data on proximate,

plastometric, petrographic and granulometric analysis of this coal charge.

Evaluating the data in the Tables 5 and, we can say that 61.2 % of the charge consists of well-cohesive coal of a middle stage of metamorphism fatty (32.6 %) and

Table 4. The stage of metamorphism and component composition of the coal charge.

№	Component name	Stage of metamorphism	Share in the charge, %
1	A	low	8.3
2	B	low	8.4
3	C	low	11.4
4	D	low	3.5
5	E	middle	7.0
6	F	middle	6.0
7	G	middle	9.4
8	H	middle	10.2
9	I	middle	18.0
10	J	middle	2.0
11	K	middle	8.6
12	L	high	7.2
Total			100.0

coking (28.6 %) coal; by 31 % - from coal of a low stage of metamorphism and 7.2 % - from lean coal of a high stage of metamorphism. The thickness of the plastic layer of the coal charge is 14 mm, its ash content is 8.3 %, the sulfur content is 1.03 %, volatile substances in the dry ash-free state are 31.6 %, vitrinite is 84 %, heterogeneous fused components are 15 %, the coefficient of grain ability according to Hardgrove - 62 units.

Table 7 presents data on yields by classes of charge size and their ash content.

Evaluating the presented data, we can say that the

average diameter of the particles of the charge is 6.2 mm, and its grinding before crushing was 52.1 %. The distribution of ash by size classes is like the distribution in concentrates, namely, its largest value (11.2 %) is characteristic of the smallest class < 0.5 mm, the smallest value (6.8 - 7.4 %) in the middle classes 0.5 - 1, 1 - 3 and 3 - 6 mm, and the intermediate value of 8.8 % is in the largest class > 6 mm.

A study was conducted to determine the actual segregation of the coal charge in the coal tower of the bat. 7 - 8 PJSC "ACP".

For this purpose, on the first day of the experiment, samples of the coal charge were taken during pumping into the coal tower. On the second day of the experiment, additional samples of the coal charge were collected from the hoppers of the coal loading machine, covering different sections and rows of the coal tower over a 6 h period.

The Table 8 shows the technological properties (A^d , S^d , V^{daf}) and particle size composition (by classes + 6; 3 - 6; 1 - 3; 0.5 - 1; less than 0.5 mm) of the coal charge to the coal tower, as well as samples of the coal charge loaded into the hoppers of the coal loading machine from different sections and rows of the coal tower.

The data of Table 8 show that the content of the 0 - 3 mm class in the samples of the coal charge, taken at an interval of 1 hour, is 78.4 - 79.7 %; ash content 8.3 - 8.5 %; total sulfur content 0.90 - 0.92 %; volatile matter in the dry ashless state is 32.1 - 32.6 %, and the average diameter of the particles is 1.80 - 1.87 mm. It is possible to ascertain the relative stability of the technological properties and particle size composition of the coal charge during its injection into the coal tower.

Table 5. Technological properties and Petrographic characteristics of the coal charge.

Proximate Analysis, %				Plastometric indices, mm		Hardgrove grindability index, units	Roga Index, units	Petrographic composition (excluding mineral impurities), %					Avg. reflectance of vitrinite, %
W^a	A^d	S^d_t	V^{daf}	X	Y	HGI	RI	Vt	Sv	I	L	$\sum FC$	R_o
1.4	8.3	1.03	31.6	22	14	62	62.2	84	0	15	1	15	1.02

Table 6. Particle size distribution of the coal charge.

Particle size distribution (mm), %									Average particle diameter, mm
> 50	50 - 25	13 - 25	6 - 13	3 - 6	1 - 3	0.5 - 1	< 0.5	< 3	d_s
0.2	3.9	8.8	15.8	19.1	20.0	7.7	24.4	52.1	6.2

The different arrangement of rows of sections affected the technological properties and particle size composition of the selected samples of coal charges (Table 9).

The data of Table 9 shows that the content of the 0 - 3 mm class in the samples of coal charges, selected from the 1st row of the 1st section, is unstable and ranges from 80.5 % (the beginning of the selection) to 64.7 -

67.4 % (the end of the experiment), i.e. the discrepancy reaches 15.8 % abs. or 24.4 % relative. This circumstance can be caused by the fact that during the pumping of the 2nd section, the largest pieces of coal can bounce off the separating slide and fall into the 1st or 2nd row of the coal tower. The content of this class in the samples taken during the experiment from the 4th and 5th rows also fluctuates, but is within technologically acceptable limits, namely from 80.3 to 84.3 %.

In the Table 10 shows the range of values of the technological properties of coal charge samples taken before and after the coal tower bat. 7 - 8 PJSC "ACP".

The data in Table 10 show that the samples collected from row 1 of section 1 differ significantly from the technological properties of the initial coal charge. Ash content decreases to 7.7 %, total sulfur content reduces to 0.87 %, and volatile matter drops to 31.3 %. This row also demonstrates the greatest variability in ash content, volatile matter, and average particle diameter.

Analysing these results leads to the conclusion that the extreme rows of the coal tower sections in batteries No. 7 - 8 exhibit significant deviations in

Table 7. Granulometric composition and quality indicators of the coal charge classes before crushing.

Particle size class, mm	Yield, %	Ash content (A^d), %
> 6	28.8	8.8
3 - 6	19.1	7.4
1 - 3	20.0	6.8
0.5 - 1	7.7	7.2
< 0.5	24.4	11.2
< 3	52.1	8.7
Total	100.0	8.3

Table 8. Technological properties and granulometric composition of the coal charge before the coal tower of the bat. 7 - 8 PJSC "ACP".

Sampling time	Particle size class, mm	Yield, %	Proximate analysis, %		
			A^d	S_t^d	V^{daf}
13:00, first day	> 6	9.1	11.5	0.63	34.8
	3 - 6	11.2	7.9	0.79	35.0
	1 - 3	22.7	7.7	0.90	33.7
	0.5 - 1	16.3	7.3	0.97	32.4
	< 0.5	40.7	9.0	1.01	30.9
	< 3	79.7	8.3	0.97	32.0
	d_s	1.87	-	-	-
	Total	100.0	8.5	0.92	32.6
14:00, first day	> 6	6.8	8.4	0.60	34.2
	3 - 6	14.8	8.9	0.74	34.9
	1 - 3	19.7	7.6	0.87	33.2
	0.5 - 1	16.3	7.2	0.94	31.8
	< 0.5	42.4	8.8	1.00	30.4
	< 3	78.4	8.2	0.95	31.4
	d_s	1.80	-	-	-
	Total	100.0	8.3	0.90	32.1

Table 9. Technological properties and granulometric composition of the coal charge from the coal tower of Bat. No. 7 - 8, 1st section, 4th row / 1st section, 1st row / 2nd section, 5th row, PJSC "ACP".

Particle size class, mm	Yield, %	Proximate analysis, %		
		A ^d	S ^d _t	V ^{daf}
Sampling 1 at 08:30, second day				
> 6	9.2 / 9.6 / 8.3	7.9 / 9.0 / 8.3	0,67 / 0.73 / 0.67	34.0 / 33.9 / 33.4
3 - 6	10.3 / 9.9 / 10.8	8.6 / 8.0 / 8.0	0.80 / 0.71 / 0.76	34.8 / 35.0 / 35.2
1 - 3	21.8 / 20.9 / 21.7	7.8 / 8.0 / 8.1	0.87 / 0.85 / 0.85	33.5 / 33.1 / 33.3
0.5 - 1	17.2 / 17.5 / 17.3	7.7 / 7.6 / 7.4	0.96 / 0.91 / 0.90	32.3 / 32.1 / 32.6
< 0.5	41.5 / 42.1 / 41.9	9.7 / 9.0 / 8.4	1.02 / 0.97 / 0.96	30.8 / 30.5 / 30.8
< 3	80.5 / 80.5 / 80.9	8.8 / 8.4 / 8.1	0.97 / 0.93 / 0.92	31.9 / 31.5 / 31.9
d _s	1.82 / 1.82 1.78	-	-	-
Total	100.0	8.7 / 8.4 / 8.1	0.92 / 0.89 / 0.88	32.4 / 32.1 / 32.3
Sampling 2 at 10:45, second day				
> 6	10.9 / 8.8 / 7.8	8.3 / 9.2 / 12.4	0.83 / 0.58 / 0.63	34.1 / 34.1 / 34.5
3 - 6	10.7 / 9.0 / 10.2	8.5 / 8.8 / 8.0	0.75 / 0.74 / 0.77	34.7 / 34.8 / 34.8
1 - 3	18.5 / 22.0 / 21.9	7.5 / 8.1 / 7.9	0.81 / 0.87 / 0.88	33.4 / 33.5 / 33.4
0.5 - 1	25.0 / 17.2 17.8	7.3 / 7.5 / 7.4	0.90 / 0.90 / 0.95	31.9 / 32.5 / 32.1
< 0.5	34.9 / 43.0 42.3	8.6 / 9.0 / 8.8	0.93 / 0.98 / 1.05	30.5 / 30.7 / 30.4
< 3	78.4 / 82.2 82.0	7.9 / 8.4 / 8.3	0.89 / 0.93 / 0.98	31.6 / 31.8 / 31.6
d _s	1.94 / 1.74 1.74	-	-	-
Total	100.0	8.0 / 8.5 / 8.6	0.87 / 0.89 / 0.93	32.2 / 32.3 / 32.1
Sampling 3 at 13:00, second day				
> 6	14.4 / 6.9 / 5.5	7.6 / 8.3 / 9.1	0.65 / 0.73 / 0.66	33.6 / 34.0 / 33.9
3 - 6	20.9 / 9.5 / 10.2	8.1 / 8.9 / 7.9	0.84 / 0.85 / 0.76	35.0 / 35.1 / 34.2
1 - 3	10.4 / 22.1 / 22.0	7.5 / 7.7 / 7.7	0.84 / 0.92 / 0.86	33.0 / 33.3 / 33.3
0.5 - 1	15.2 / 18.6 / 18.5	7.4 / 7.4 / 7.3	0.94 / 0.96 / 0.91	31.8 / 32.7 / 31.9
< 0.5	39.1 / 42.9 / 43.8	8.9 / 9.0 / 8.6	0.99 / 1.06 / 0.97	30.7 / 30.1 / 30.7
< 3	64.7 / 83.6 / 84.3	8.9 / 8.3 / 8.1	0.99 / 0.84 / 0.93	30.7 / 31.5 / 31.6
d _s	2.44 / 1.63 1.56	-	-	-
Total	100.0	8.3 / 8.4 / 8.1	0.95 / 0.97 / 0.90	31.3 / 32.0 / 32.0
Sampling 4 at 15:20, second day				
> 6	19.4 / 9.0 / 8.4	6.6 / 10.0 / 10.2	0.61 / 0.68 / 0.78	33.0 / 34.6 / 33.9
3 - 6	13.2 / 10.7 / 11.3	7.8 / 8.4 / 8.1	0.81 / 0.80 / 0.84	34.8 / 34.8 / 34.3
1 - 3	20.2 / 22.8 / 22.8	7.6 / 7.6 / 7.7	0.91 / 0.88 / 0.91	33.6 / 33.4 / 32.9
0.5 - 1	13.3 / 18.1 / 17.6	7.0 / 7.3 / 7.5	0.96 / 0.94 / 0.96	32.5 / 31.9 / 32.8
< 0.5	33.9 / 39.4 / 39.9	8.7 / 8.8 / 9.1	1.05 / 1.00 / 1.03	30.7 / 30.7 / 30.2
< 3	67.4 / 80.3 / 80.3	8.0 / 8.1 / 8.4	0.99 / 0.95 / 0.98	31.9 / 31.7 / 31.5
d _s	2.64 / 1.85 / 1.85	-	-	-
Total	100.0	7.7 / 8.3 / 8.5	0.89 / 0.91 / 0.95	32.5 / 32.3 / 32.0

Table 10. Range of technological properties of coal charge samples.

Parameter	Range of values			
	A^d , %	S^d_{tr} , %	V^{daf} , %	d_s , mm
Charge before the tower	8.3 - 8.5	0.90 - 0.92	32.1 - 32.6	1.80 - 1.87
Charge in coal tower, 1st section, 1st row	7.7 - 8.7	0.87 - 0.95	31.3 - 32.5	1.82 - 2.64
Charge in coal tower, 1st section, 4th row	8.3 - 8.5	0.89 - 0.97	32.0 - 32.3	1.63 - 1.85
Charge in coal tower, 2nd section, 5th row	8.1 - 8.6	0.88 - 0.95	32.0 - 32.3	1.56 - 1.83

coal charge quality parameters compared to the initial values during loading. These findings, obtained under real operating conditions at a coking plant, fully confirm the conclusions of Zhu et al., where modelling demonstrated that larger particles tend to settle farther along the height of the layer [18]. Similar conclusions were drawn in studies [12] and [19]. The example of Numerical investigation of the effects of size segregation on pulverized coal combustion in a blast furnace also demonstrates the occurrence of separate problem zones of inhomogeneity [32]. Liu et al. also found three such groups of segregated behaviour by size and explained it by the effect of size on the distribution structures of elements in coal particles [33], instead, Chen et al. draw attention to the significant influence of vibrations on the movement of particles and air flow during the separation of small coal particles [34]. Undoubtedly, in our case, at the speed of feeding the coal charge by the conveyor belt of 400 t h⁻¹, these factors also had an impact. To reduce the negative segregation, Gao et al. proposed to solve with the help of hydrothermal carbonization [35].

Summarizing the results, we note that it is advisable to develop recommendations for the elimination of segregation and equalize coal charge quality parameters, as well as to apply Algorithms for segregation control (as proposed by Ganguli and Yingling using the MWE / MWN method [36] for large batches of coal and the time series based method [37] for small batches), which should lead to stabilization of the blast furnace coke quality obtained at the enterprise.

CONCLUSIONS

This study examines coal segregation under real industrial conditions at PJSC “ACP,” focusing on particle size and key quality parameters. Conducted in a two-section coal tower with a stationary reversible

conveyor and chutes, coal quality was assessed both before feeding and across different tower sections. The quality indicators of the coal charge were determined according to the current standardized methods both directly from the conveyor belt before feeding to the coal tower, and from different sections and rows of the coal tower. The research highlights significant deviations in coal charge quality across tower sections and rows, particularly at the periphery. As a result, the following main conclusions were obtained:

- Ash content distribution across particle size classes is uneven. The 25 - 50 mm size class exhibited the highest variability (6.8 - 32.1 %), with an average ash content of 13.1 %. Minimal ash content was observed in the 0.5 - mm (7.3 %), 1 - 3 mm (6.9 %), and 3 - 6 mm (7.3 %) size classes. The finest particle class (< 0.5 mm) had significantly higher ash content, averaging 10.9 % and reaching up to 15.1 %.
- The technological properties and granulometric composition of the coal charge remained relatively stable during loading into the coal tower. For samples collected hourly, the 0 - 3 mm size class content was 78.4 - 79.7 %, ash content ranged from 8.3 % to 8.5 %, total sulfur content was 0.90 - 0.92 %, volatile matter (dry ash-free) was 32.1 - 32.6 %, and the average particle diameter was 1.80 - 1.87 mm.
- Despite stable initial parameters, significant deviations were observed in the rows of the coal tower. The extreme rows showed the greatest variability in parameters such as average particle diameter (d_s), volatile matter (V^{daf}), and ash content (A^d).
- Addressing the significant deviations in coal charge quality observed in the extreme rows of the coal tower is necessary. Implementing technological measures to minimize segregation and equalize charge quality parameters as well as to apply algorithms for segregation control should stabilize the quality of blast furnace coke

produced at the plant.

It should be noted that all data were obtained on the raw material base and in the conditions of the specific above-mentioned enterprise, so in the future it would be advisable to conduct similar studies on other operating coke oven enterprises. This will allow diversifying the raw material base, technological and structural features of coal preparation and solving the problem of deviation of segregative parameters of the charge quality.

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